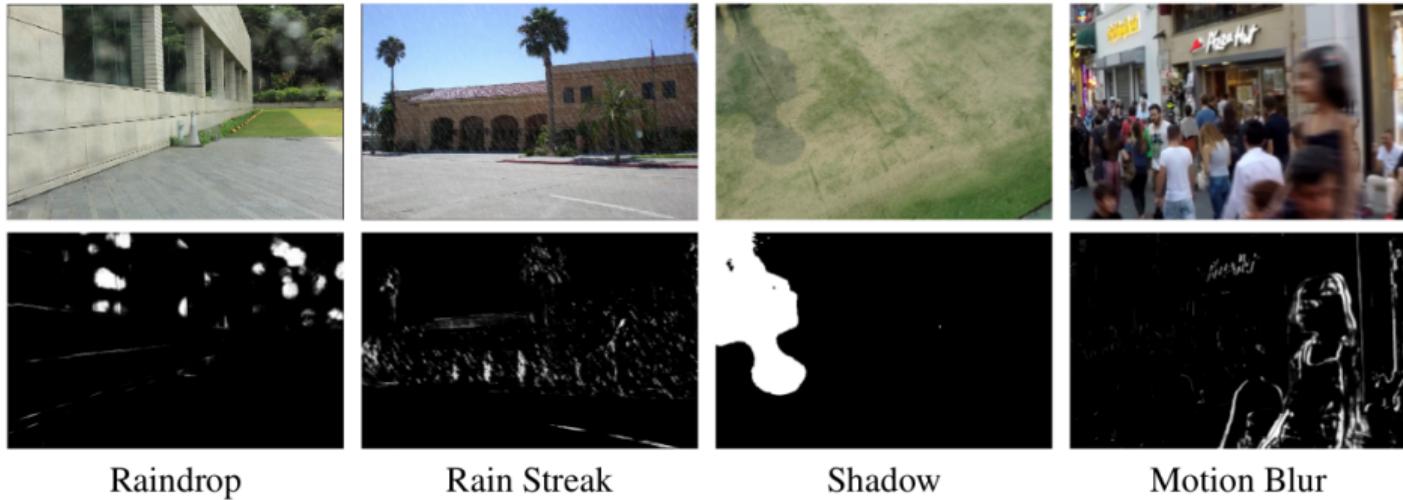


Spatially-Adaptive Image Restoration using Distortion-Guided Networks

IEEE/CVF ICCV 2021



Kuldeep Purohit¹

¹ Michigan State University

Maitreya Suin²

A. N. Rajagopalan²

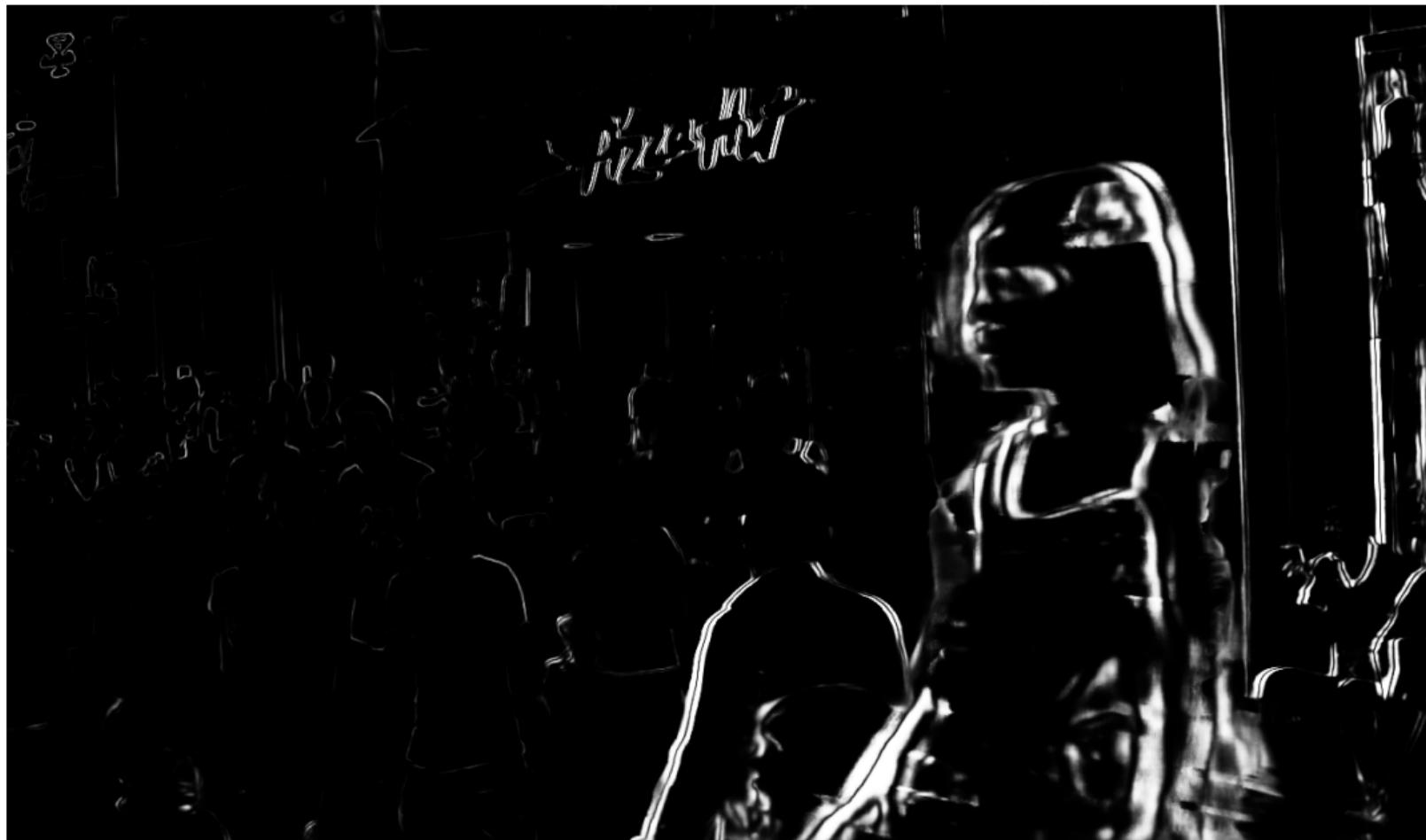
² Indian Institute of Technology Madras

Vishnu Naresh Boddeti¹





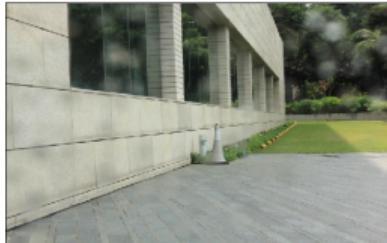








Commonality: Spatially sparse distortions.



Raindrop



Rain Streak



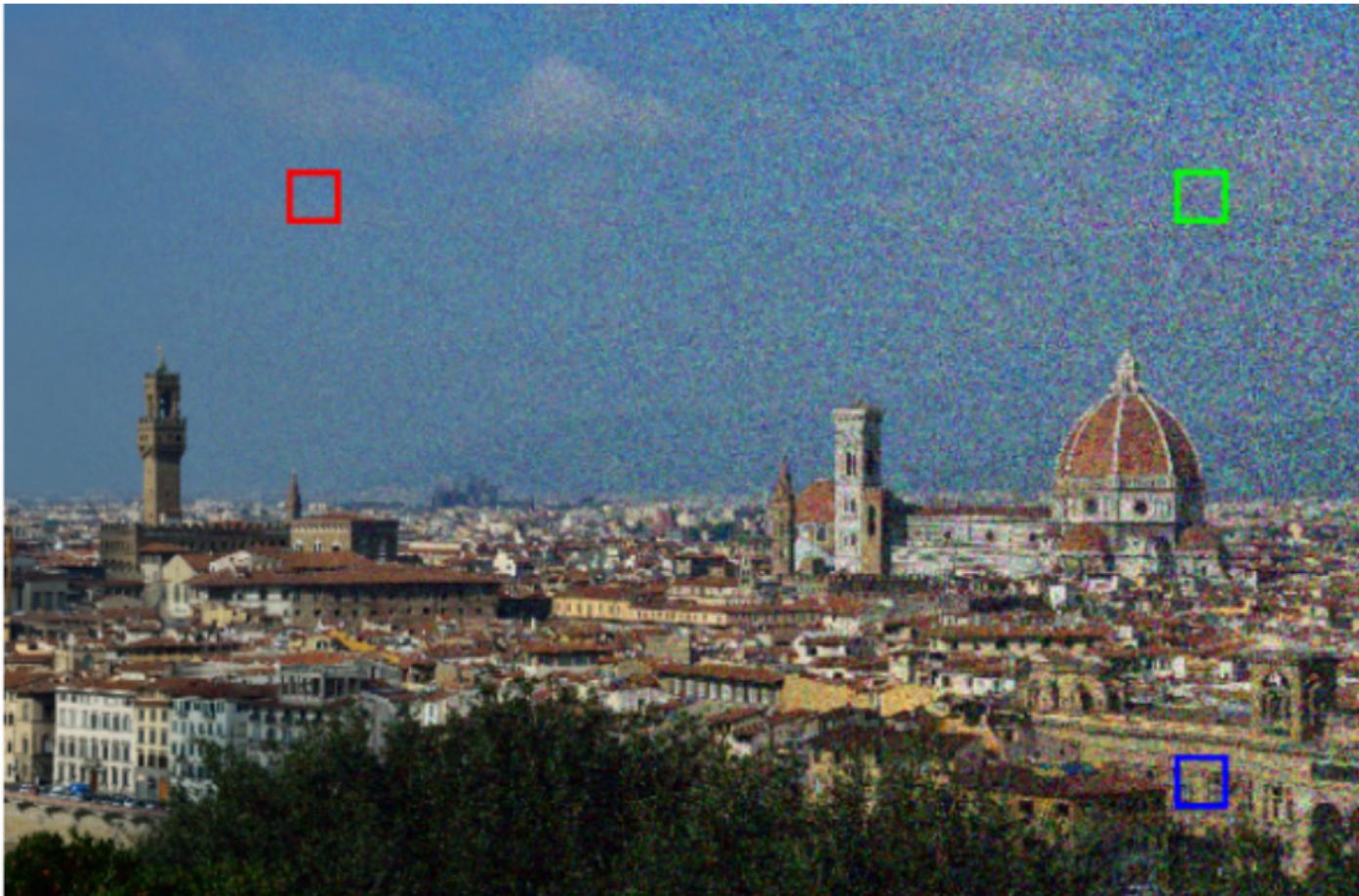
Shadow



Motion Blur

Figure: Visualization of degradation masks. The two rows show degraded input images and corresponding predicted masks.

Motivation for Spatially-Adaptive Model



Motivation for Spatially-Adaptive Model



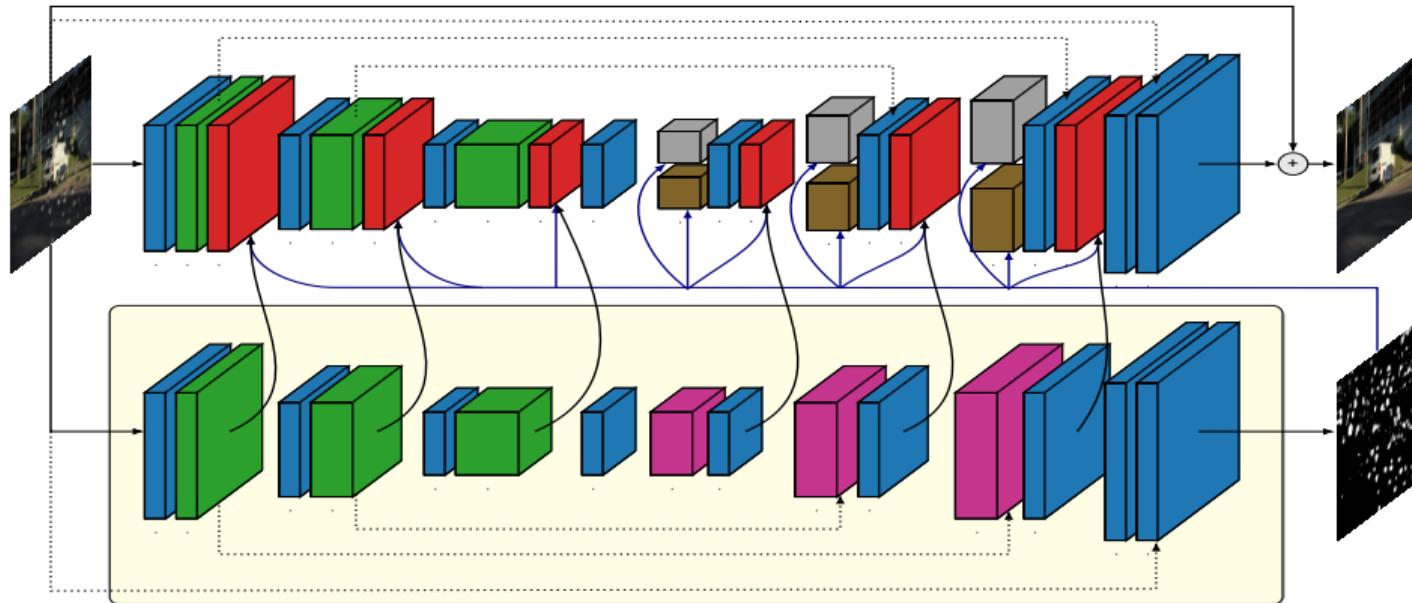
Input

5 layers

12 layers

20 layers

Proposed Architecture



Legend



Convolution
Layer



Dense
Convolution
Block



Spatial
Feature
Modulator



Sparse
Convolution
Module



Sparse
Non-Local
Module

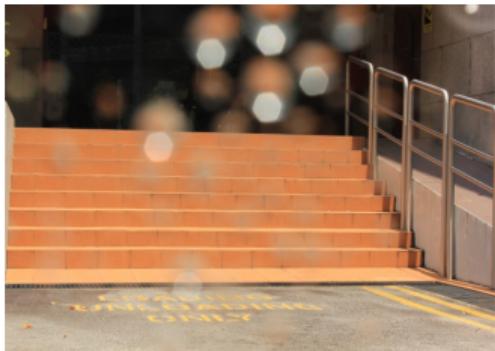


Localization
Network (Net_L)



\equiv
Dense
Decoder
Module

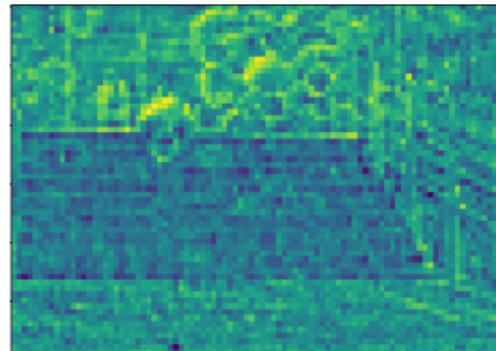
Mask guided Sparse Convolution (SC) and Spatial Feature Modulator (SFM)



Input Image

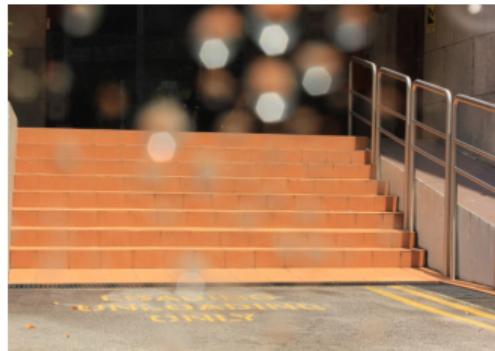


Mask \mathcal{M}



Intermediate Feature map F

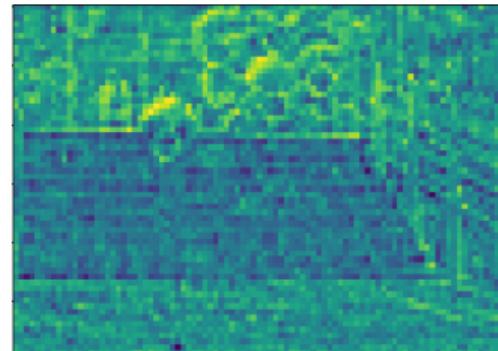
Mask guided Sparse Convolution (SC) and Spatial Feature Modulator (SFM)



Input Image



Mask \mathcal{M}

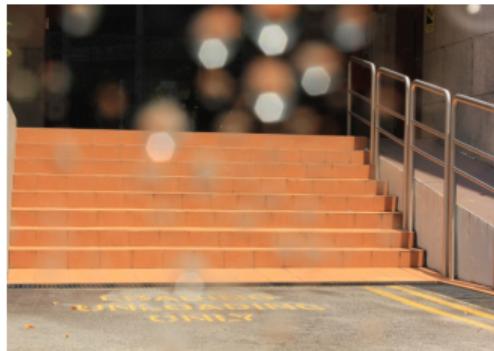


Intermediate Feature map F

- SC estimates sparse feature map F^S using weights $K \in \mathbb{R}^{C_{in} \times C_{out} \times k \times k}$ as

$$F_p^S = \begin{cases} 0 & \mathcal{M}_p = 0 \\ \sum_{p' \in R_k} K'_{p'} F_{p+p'} & \mathcal{M}_q, \mathcal{M}_p = 1, \end{cases} \quad (1)$$

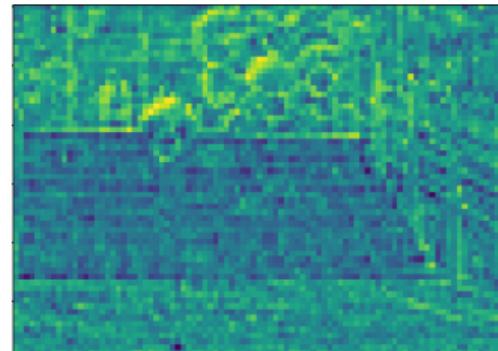
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Input Image



Mask \mathcal{M}



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- Studies show the correspondence between
 - Feature mean \rightarrow global semantic information.
 - Feature variance \rightarrow local texture.

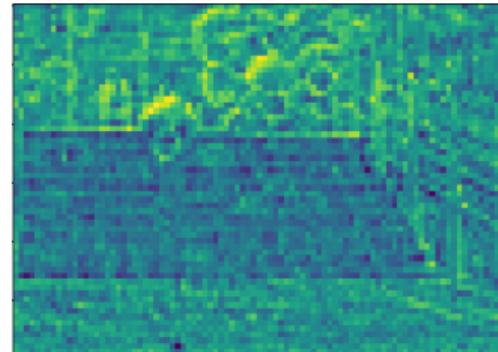
Mask guided Sparse Convolution (SC) and Spatial Feature Modulator (SFM)



Input Image



Mask \mathcal{M}



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- Studies show the correspondence between
 - Feature mean \rightarrow global semantic information.
 - Feature variance \rightarrow local texture.
- SFM modulates features at $\mathcal{M} = 1$ to match the feature statistics of features at $\mathcal{M} = 0$.

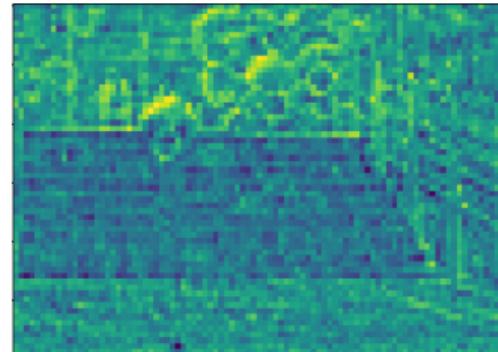
Mask guided Sparse Convolution (SC) and Spatial Feature Modulator (SFM)



Input Image



Mask \mathcal{M}



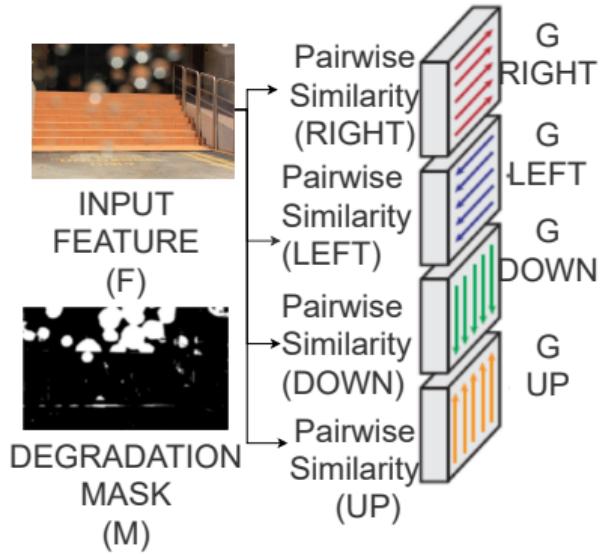
Intermediate Feature map F

- SC estimates sparse feature map F^S using weights $K \in \mathbb{R}^{C_{in} \times C_{out} \times k \times k}$ as

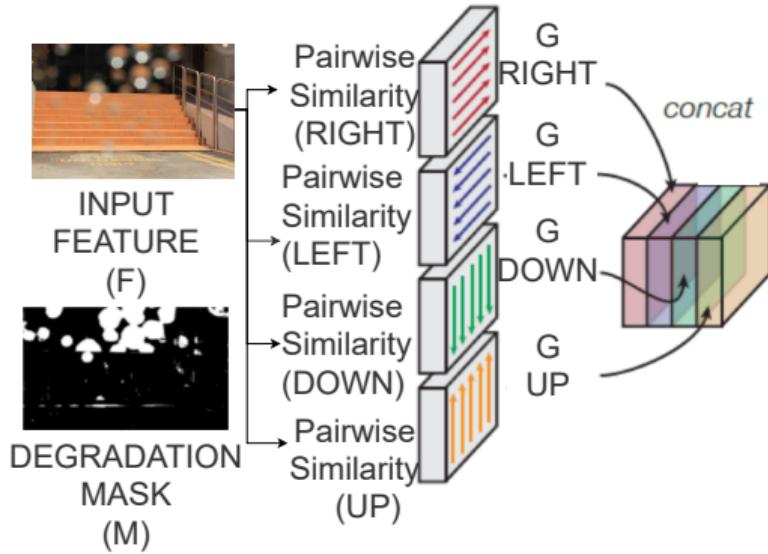
$$F_p^S = \begin{cases} 0 & \mathcal{M}_p = 0 \\ \sum_{p' \in R_k} K'_{p'} F_{p+p'} & \mathcal{M}_q, \mathcal{M}_p = 1, \end{cases} \quad (1)$$

- Studies show the correspondence between
 - Feature mean \rightarrow global semantic information.
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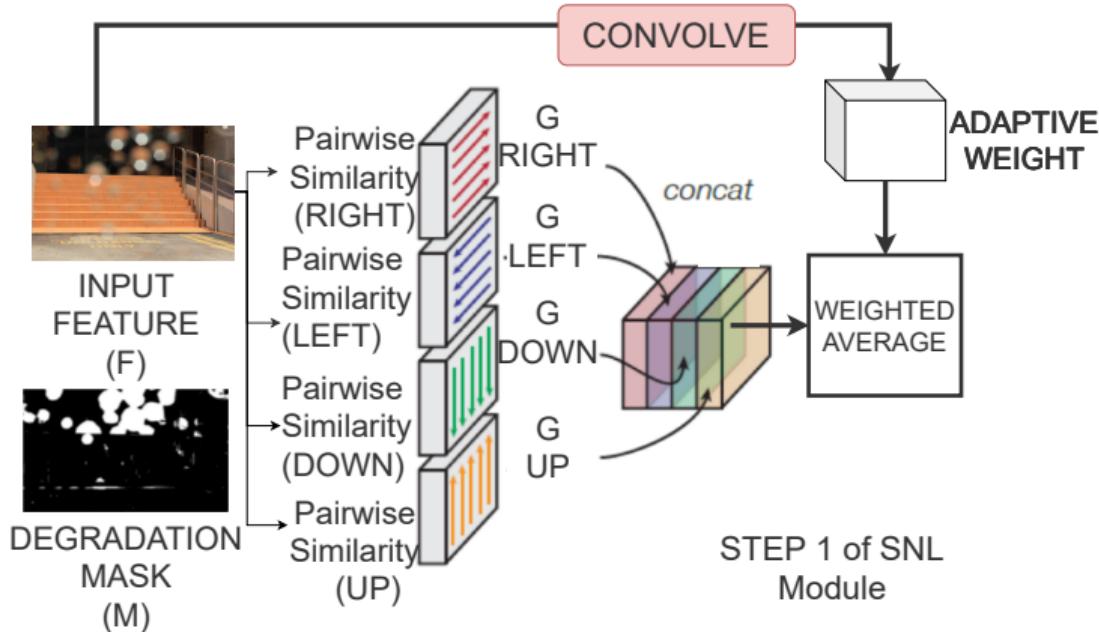
Sparse Non Local Module



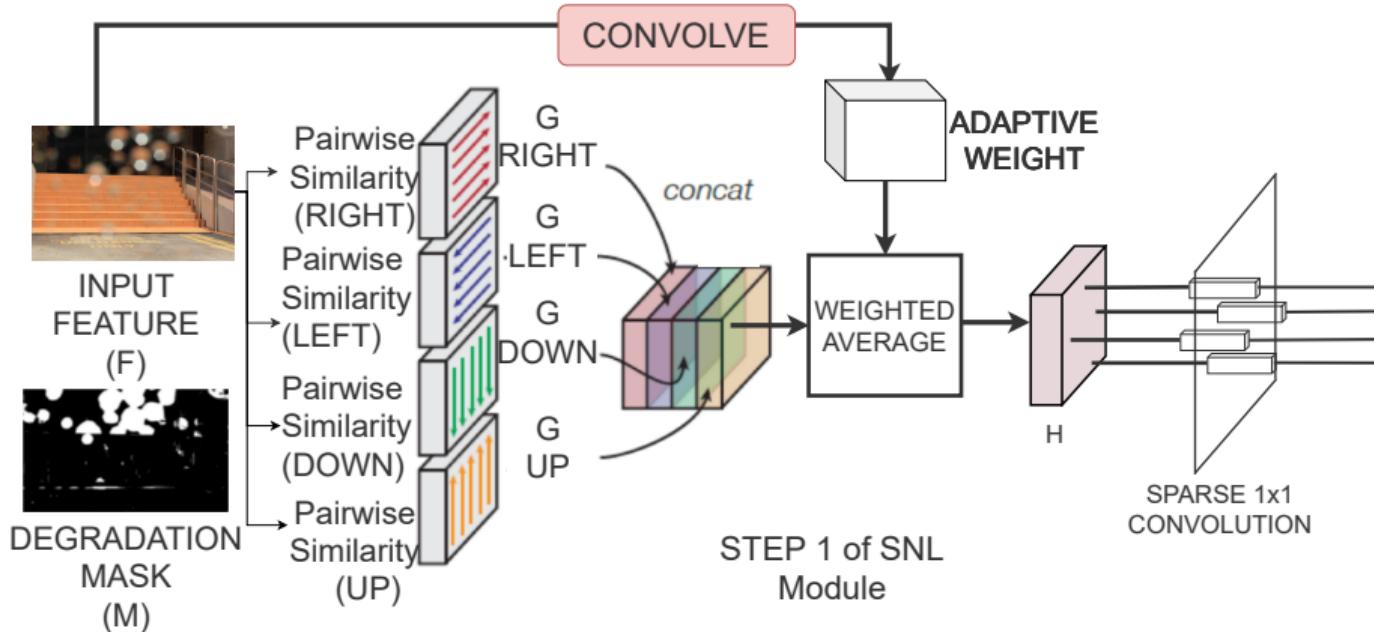
Sparse Non Local Module



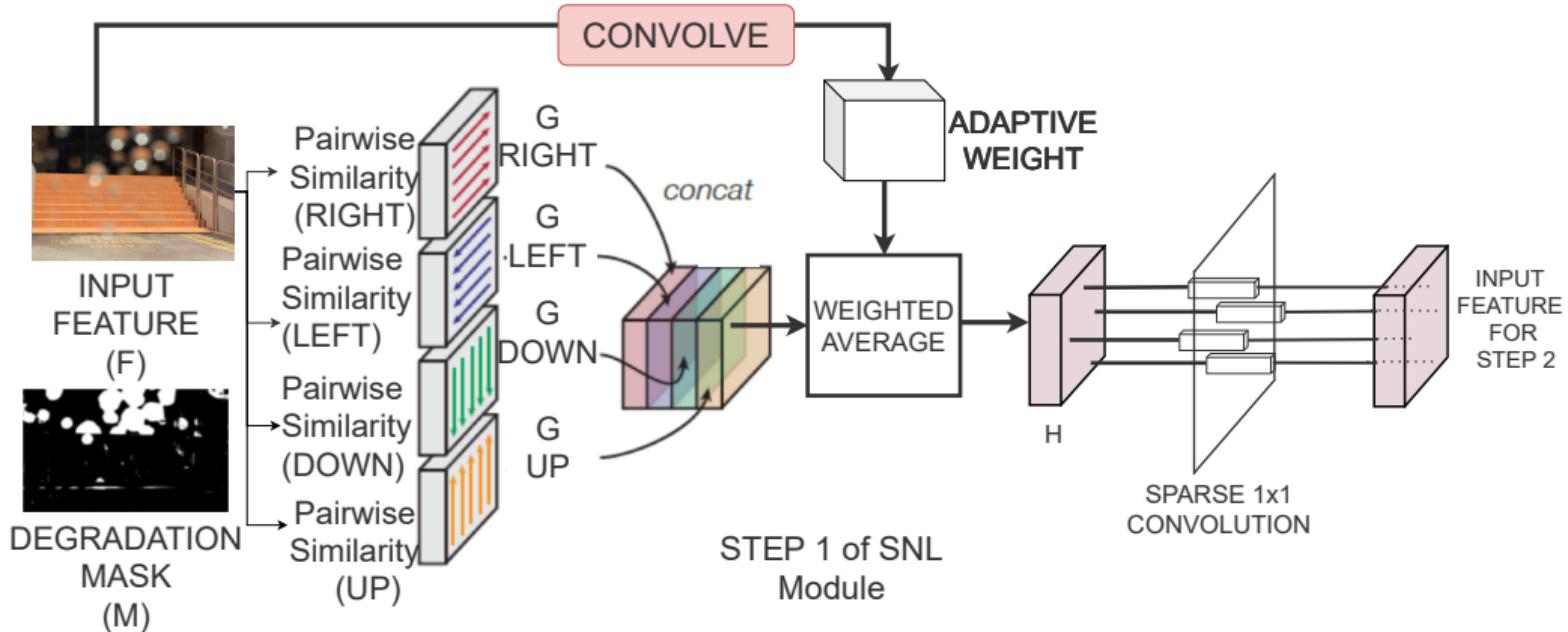
Sparse Non Local Module



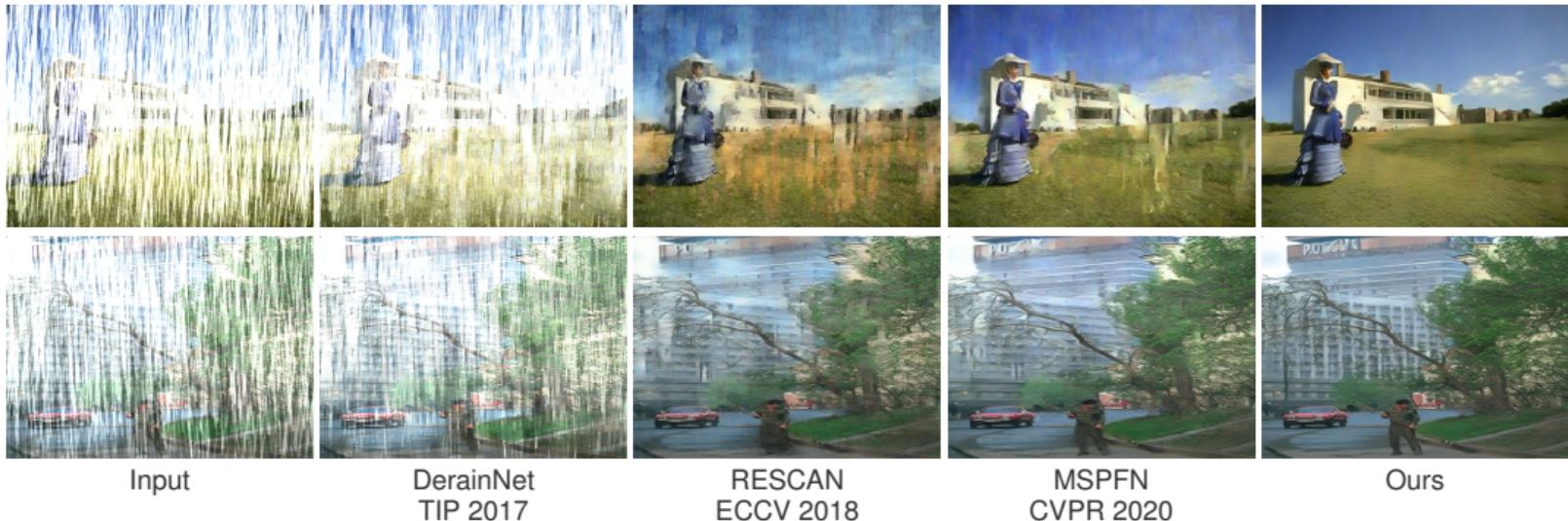
Sparse Non Local Module



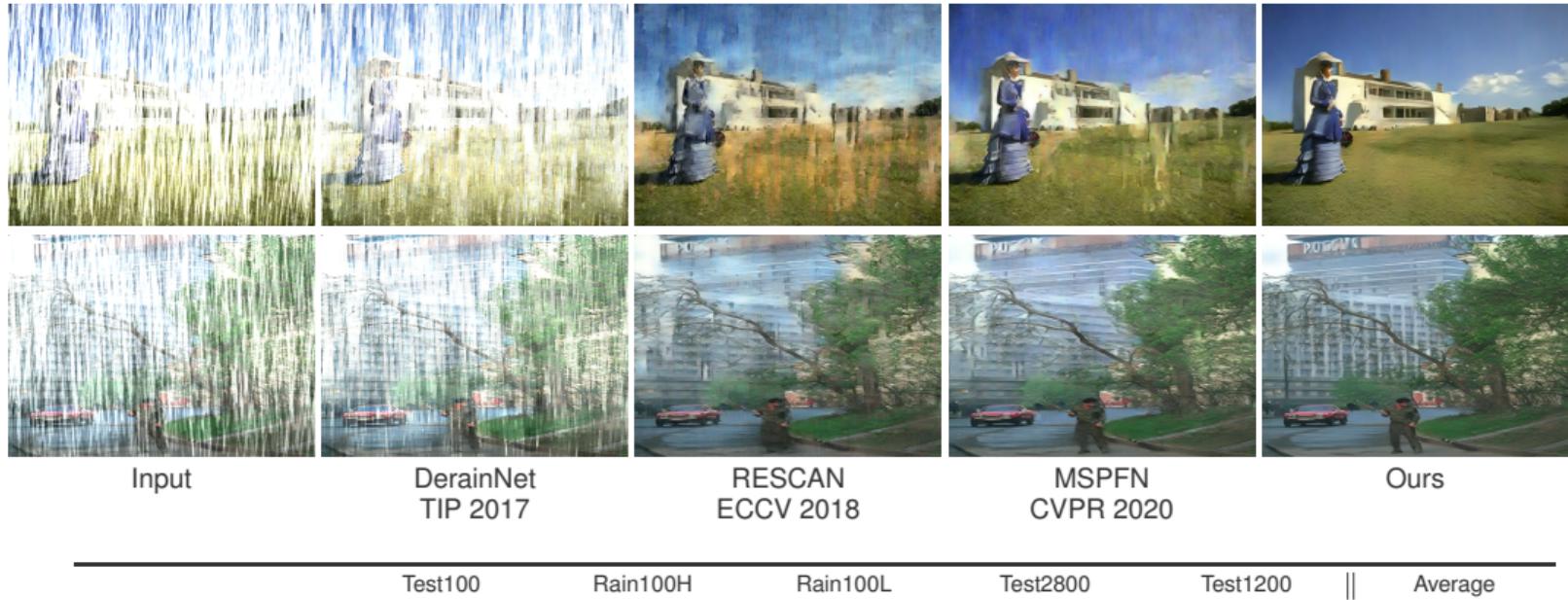
Sparse Non Local Module



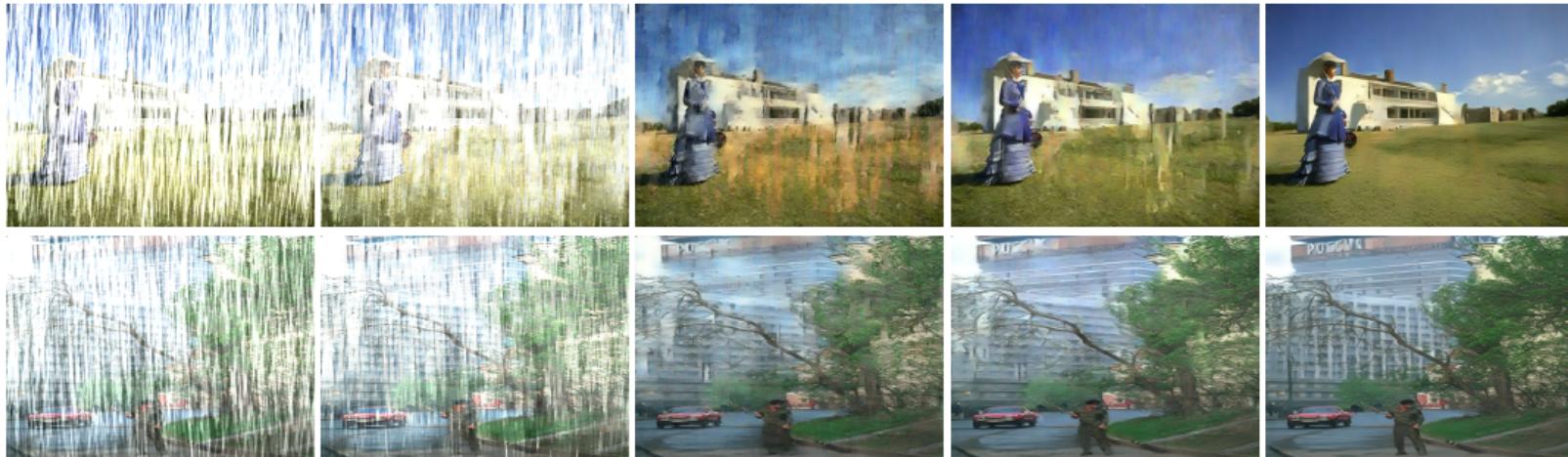
Qualitative Results for Rain-Streak Removal



Qualitative Results for Rain-Streak Removal



Qualitative Results for Rain-Streak Removal



Input

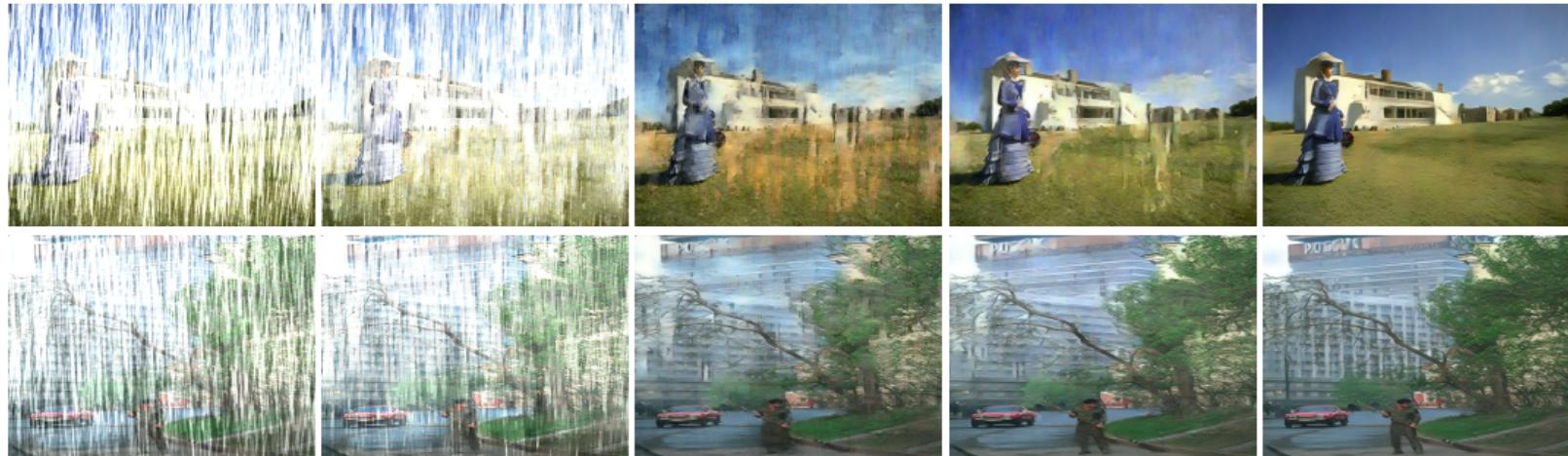
DerainNet
TIP 2017

RESCAN
ECCV 2018

MSPFN
CVPR 2020

Ours

Qualitative Results for Rain-Streak Removal



Input

DerainNet
TIP 2017

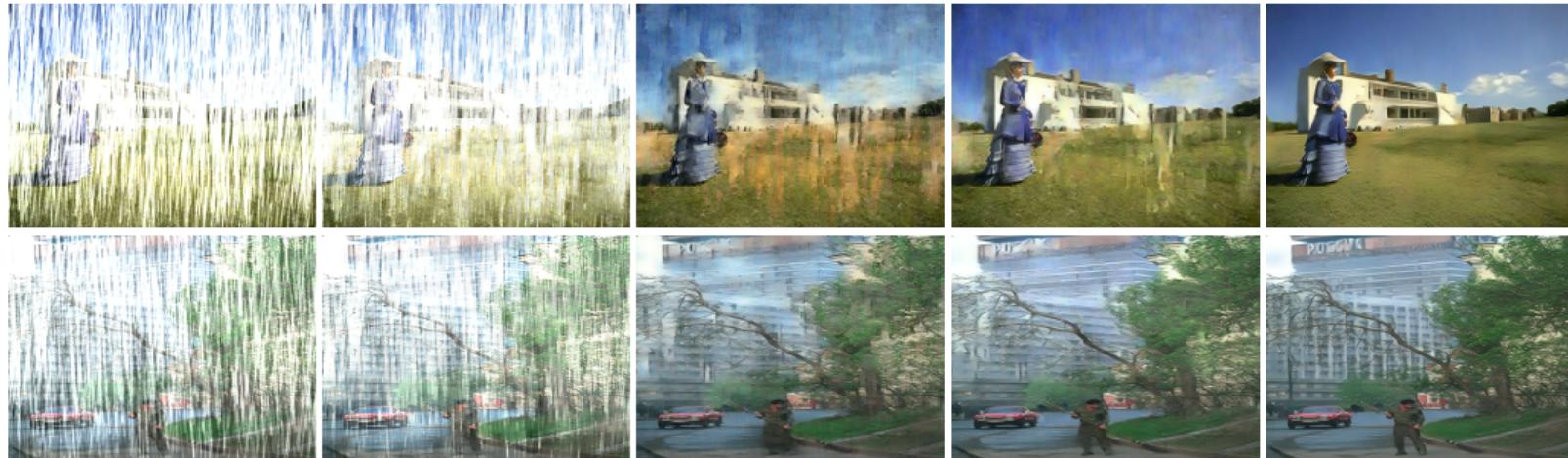
RESCAN
ECCV 2018

MSPFN
CVPR 2020

Ours

| Methods | Venue | Test100 | | Rain100H | | Rain100L | | Test2800 | | Test1200 | | Average | |
|-----------|-----------|---------|--------|----------|--------|----------|--------|----------|--------|----------|--------|---------|--------|
| | | PSNR ↑ | SSIM ↑ | PSNR ↑ | SSIM ↑ | PSNR ↑ | SSIM ↑ | PSNR ↑ | SSIM ↑ | PSNR ↑ | SSIM ↑ | PSNR ↑ | SSIM ↑ |
| DerainNet | TIP 2017 | 22.77 | 0.810 | 14.92 | 0.592 | 27.03 | 0.884 | 24.31 | 0.861 | 23.38 | 0.835 | 22.48 | 0.796 |
| SEMI | CVPR 2019 | 22.35 | 0.788 | 16.56 | 0.486 | 25.03 | 0.842 | 24.43 | 0.782 | 26.05 | 0.822 | 22.88 | 0.744 |
| DIDMDN | CVPR 2018 | 22.56 | 0.818 | 17.35 | 0.524 | 25.23 | 0.741 | 28.13 | 0.867 | 29.65 | 0.901 | 24.58 | 0.770 |
| UMRL | CVPR 2019 | 24.41 | 0.829 | 26.01 | 0.832 | 29.18 | 0.923 | 29.97 | 0.905 | 30.55 | 0.910 | 28.02 | 0.880 |
| RESCAN | ECCV 2018 | 25.00 | 0.835 | 26.36 | 0.786 | 29.80 | 0.881 | 31.29 | 0.904 | 30.51 | 0.882 | 28.59 | 0.857 |
| PreNet | CVPR 2019 | 24.81 | 0.851 | 26.77 | 0.858 | 32.44 | 0.950 | 31.75 | 0.916 | 31.36 | 0.911 | 29.42 | 0.897 |
| MSPFN | CVPR 2020 | 27.50 | 0.876 | 28.66 | 0.860 | 32.40 | 0.933 | 32.82 | 0.930 | 32.39 | 0.916 | 30.75 | 0.903 |

Qualitative Results for Rain-Streak Removal



Input

DerainNet
TIP 2017

RESCAN
ECCV 2018

MSPFN
CVPR 2020

Ours

| Methods | Venue | Test100 | | Rain100H | | Rain100L | | Test2800 | | Test1200 | | Average | |
|-----------|-----------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | | PSNR ↑ | SSIM ↑ |
| DerainNet | TIP 2017 | 22.77 | 0.810 | 14.92 | 0.592 | 27.03 | 0.884 | 24.31 | 0.861 | 23.38 | 0.835 | 22.48 | 0.796 |
| SEMI | CVPR 2019 | 22.35 | 0.788 | 16.56 | 0.486 | 25.03 | 0.842 | 24.43 | 0.782 | 26.05 | 0.822 | 22.88 | 0.744 |
| DIDMDN | CVPR 2018 | 22.56 | 0.818 | 17.35 | 0.524 | 25.23 | 0.741 | 28.13 | 0.867 | 29.65 | 0.901 | 24.58 | 0.770 |
| UMRL | CVPR 2019 | 24.41 | 0.829 | 26.01 | 0.832 | 29.18 | 0.923 | 29.97 | 0.905 | 30.55 | 0.910 | 28.02 | 0.880 |
| RESCAN | ECCV 2018 | 25.00 | 0.835 | 26.36 | 0.786 | 29.80 | 0.881 | 31.29 | 0.904 | 30.51 | 0.882 | 28.59 | 0.857 |
| PreNet | CVPR 2019 | 24.81 | 0.851 | 26.77 | 0.858 | 32.44 | 0.950 | 31.75 | 0.916 | 31.36 | 0.911 | 29.42 | 0.897 |
| MSPFN | CVPR 2020 | 27.50 | 0.876 | 28.66 | 0.860 | 32.40 | 0.933 | 32.82 | 0.930 | 32.39 | 0.916 | 30.75 | 0.903 |
| (Ours) | | 30.35 | 0.909 | 30.95 | 0.892 | 36.93 | 0.969 | 33.34 | 0.936 | 33.04 | 0.922 | 32.91 | 0.926 |

Qualitative Results for Motion Blur Removal



Blurred Image



Blurred patch



Purohit et al. CVPR 20



Ours

Qualitative Results for Motion Blur Removal



Blurred Image



Blurred patch



Purohit et al. CVPR 20



Ours



Blurred Image



Blurred patch



Rim et al. ECCV 20



Ours

Quantitative Results for Motion Blur Removal

Table: Our method is trained only on the GoPro dataset and directly applied to the test images of HIDE and RealBlur-J datasets. PSNR[‡] scores were obtained after training and testing on RealBlur-J dataset.

| Method | Venue | GoPro | | HIDE | | RealBlur-J | | |
|--------|-------|-------|------|------|------|------------|------|-------------------|
| | | PSNR | SSIM | PSNR | SSIM | PSNR | SSIM | PSNR [‡] |
| | | | | | | | | |

Quantitative Results for Motion Blur Removal

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| Method | Venue | GoPro | | HIDE | | RealBlur-J | | |
|----------------|-----------|--------------|--------------|--------------|--------------|--------------|--------------|-------------------|
| | | PSNR | SSIM | PSNR | SSIM | PSNR | SSIM | PSNR [‡] |
| Xu et al. | CVPR 2013 | 21.00 | 0.741 | - | - | 27.14 | 0.830 | |
| DeblurGAN | CVPR 2018 | 28.70 | 0.858 | 24.51 | 0.871 | 27.97 | 0.834 | |
| Nah et al. | CVPR 2017 | 29.08 | 0.914 | 25.73 | 0.874 | 27.87 | 0.827 | |
| Zhang et al. | CVPR 2018 | 29.19 | 0.931 | - | - | 27.80 | 0.847 | |
| DeblurGAN-v2 | ICCV 2019 | 29.55 | 0.934 | 26.61 | 0.875 | <u>28.70</u> | 0.866 | 29.69 |
| SRN | CVPR 2018 | 30.26 | 0.934 | 28.36 | 0.915 | 28.56 | <u>0.867</u> | <u>31.38</u> |
| Shen et al. | ICCV 2019 | - | - | 28.89 | 0.930 | - | - | |
| DBGAN | CVPR 2020 | 31.10 | 0.942 | 28.94 | 0.915 | - | - | |
| MT-RNN | ECCV 2020 | 31.15 | 0.945 | 29.15 | 0.918 | - | - | |
| DMPHN | CVPR 2019 | 31.20 | 0.940 | 29.09 | 0.924 | 28.42 | 0.860 | |
| Purohit et al. | CVPR 2020 | <u>31.85</u> | <u>0.948</u> | <u>29.98</u> | <u>0.930</u> | - | - | |

Quantitative Results for Motion Blur Removal

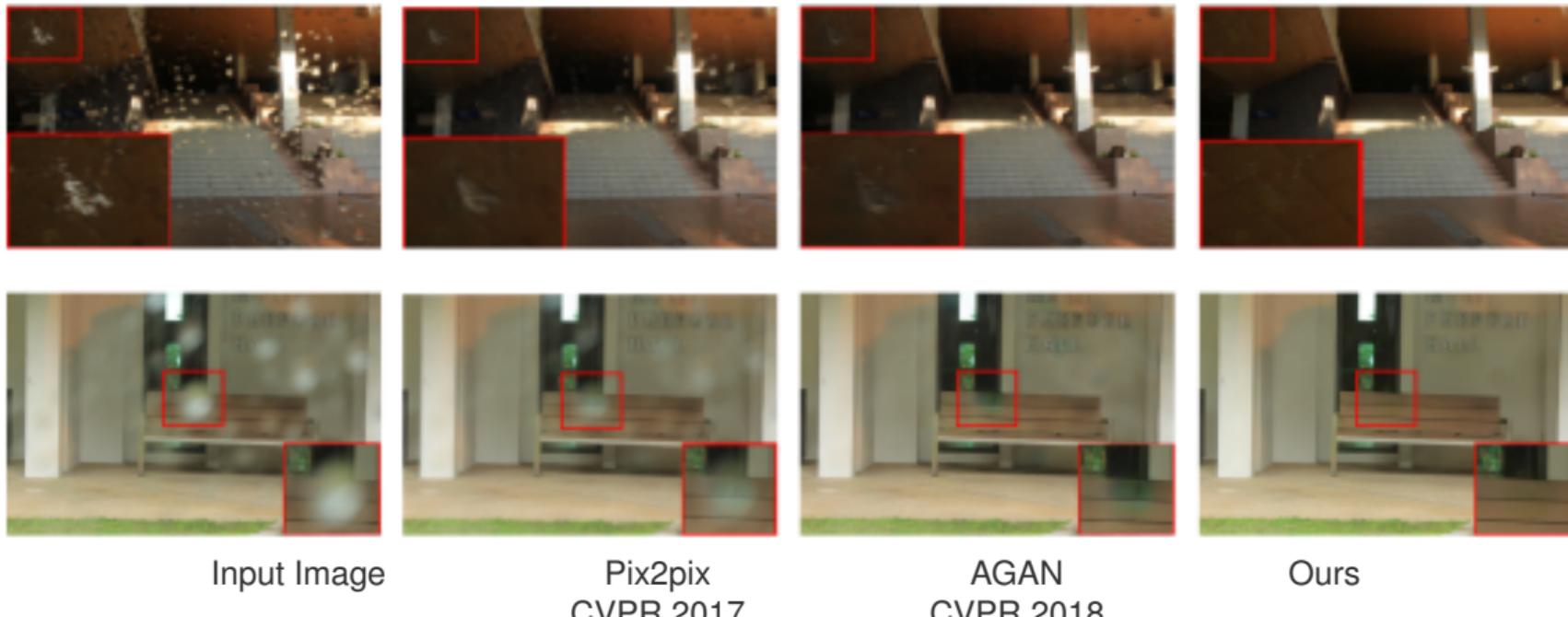
Table: Our method is trained only on the GoPro dataset and directly applied to the test images of HIDE and RealBlur-J datasets. PSNR[‡] scores were obtained after training and testing on RealBlur-J dataset.

| Method | Venue | GoPro | | HIDE | | RealBlur-J | | |
|----------------|-----------|--------------|--------------|--------------|--------------|--------------|--------------|-------------------|
| | | PSNR | SSIM | PSNR | SSIM | PSNR | SSIM | PSNR [‡] |
| Xu et al. | CVPR 2013 | 21.00 | 0.741 | - | - | 27.14 | 0.830 | |
| DeblurGAN | CVPR 2018 | 28.70 | 0.858 | 24.51 | 0.871 | 27.97 | 0.834 | |
| Nah et al. | CVPR 2017 | 29.08 | 0.914 | 25.73 | 0.874 | 27.87 | 0.827 | |
| Zhang et al. | CVPR 2018 | 29.19 | 0.931 | - | - | 27.80 | 0.847 | |
| DeblurGAN-v2 | ICCV 2019 | 29.55 | 0.934 | 26.61 | 0.875 | <u>28.70</u> | 0.866 | 29.69 |
| SRN | CVPR 2018 | 30.26 | 0.934 | 28.36 | 0.915 | 28.56 | <u>0.867</u> | <u>31.38</u> |
| Shen et al. | ICCV 2019 | - | - | 28.89 | 0.930 | - | - | |
| DBGAN | CVPR 2020 | 31.10 | 0.942 | 28.94 | 0.915 | - | - | |
| MT-RNN | ECCV 2020 | 31.15 | 0.945 | 29.15 | 0.918 | - | - | |
| DMPHN | CVPR 2019 | 31.20 | 0.940 | 29.09 | 0.924 | 28.42 | 0.860 | |
| Purohit et al. | CVPR 2020 | <u>31.85</u> | <u>0.948</u> | <u>29.98</u> | <u>0.930</u> | - | - | |
| Ours | | 32.06 | 0.953 | 30.29 | 0.931 | 28.81 | 0.875 | 31.82 |

Qualitative Results for Raindrop Removal



Qualitative Results for Raindrop Removal



Input Image

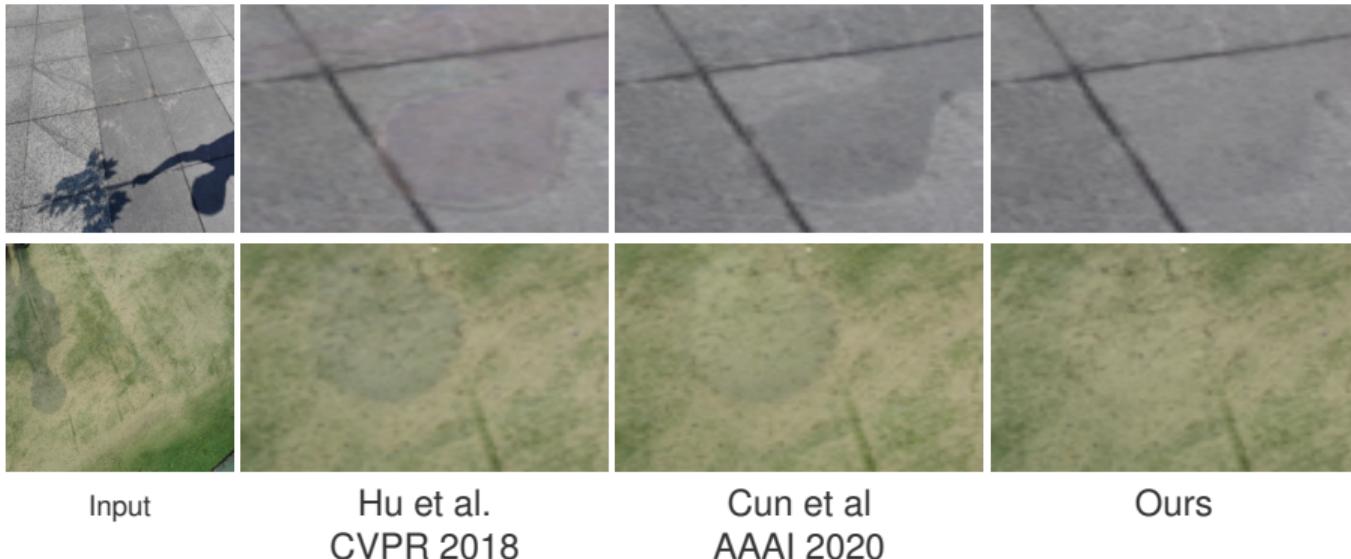
Pix2pix
CVPR 2017

AGAN
CVPR 2018

Ours

| Method | Eigen ICCV 2013 | Pix2pix CVPR 2017 | AGAN CVPR 2018 | DuRN CVPR 2019 | Quan ICCV 2019 | Ours |
|--------|--------------------|----------------------|-------------------|-------------------|-------------------|---------------|
| PSNR | 28.59 | 30.59 | 31.51 | 31.24 | 31.44 | 32.73 |
| SSIM | 0.6726 | 0.8075 | 0.9213 | 0.9259 | 0.9263 | 0.9410 |

Results for Shadow Removal



Results for Shadow Removal

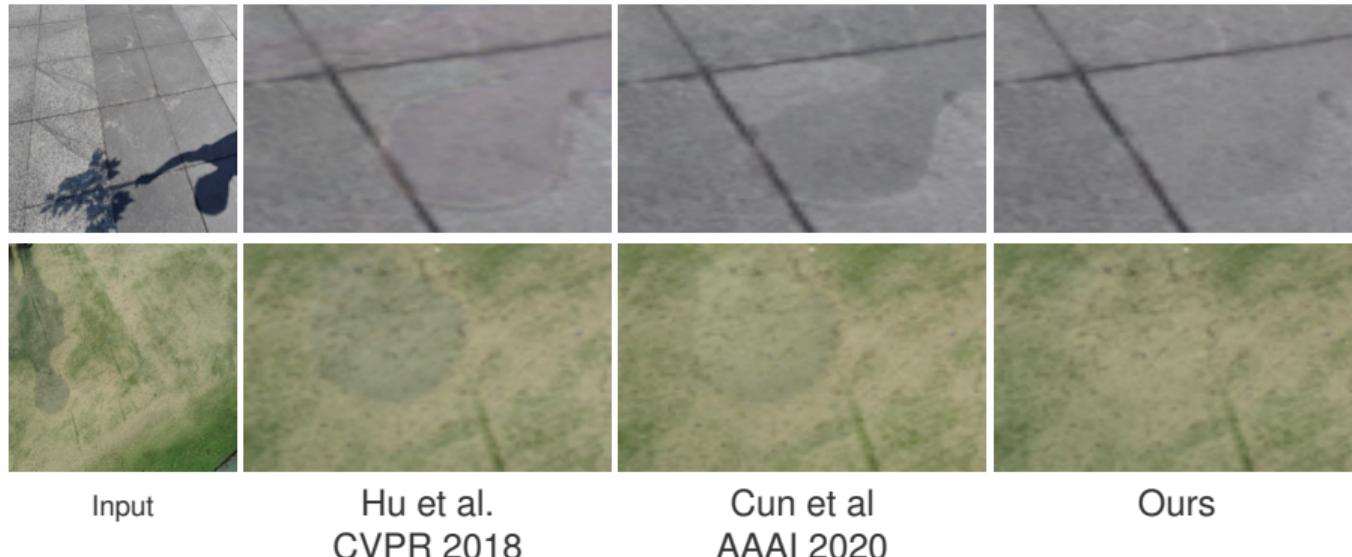


Table: Shadow removal results on ISTD Dataset. Subscripts S and NS indicate shadow and non-shadow regions.

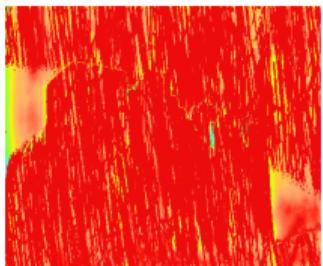
| Metric | Input | Yang et al. TIP 2012 | Gouo et al. TPAMI 2012 | Gong et al. BMVC 2014 | Wang et al. CVPR 2018 | Hu et al. CVPR 2018 | Zhang et al. AAAI 2020 | Cun et al. AAAI 2020 | Ours |
|--------------------|-------|-------------------------|---------------------------|--------------------------|--------------------------|------------------------|---------------------------|-------------------------|-------------|
| RMSE_S | 32.12 | 19.82 | 18.95 | 14.98 | 10.33 | 9.48 | 8.99 | 8.14 | 8.05 |
| RMSE_{NS} | 7.19 | 14.83 | 7.46 | 7.29 | 6.93 | 6.14 | 6.33 | 6.04 | 5.47 |
| RMSE | 10.97 | 15.63 | 9.30 | 8.53 | 7.47 | 6.67 | 6.95 | 6.37 | 5.88 |

Visualizing Reconstruction Errors for Rain-Streak Removal

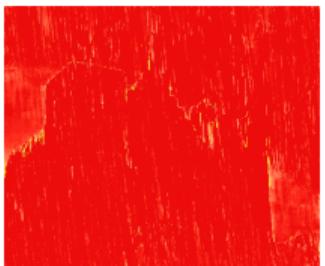
Input Rainy Image



DDN
CVPR 17



RESCAN
CVPR 19



RCDNet
CVPR 20

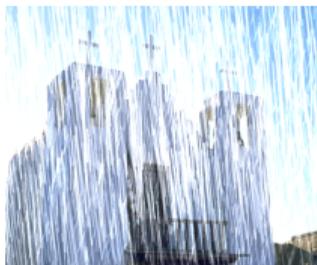


Ours

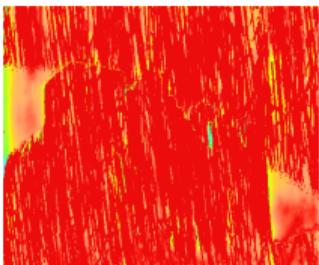


Visualizing Reconstruction Errors for Rain-Streak Removal

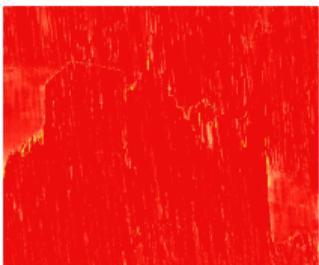
Input Rainy Image



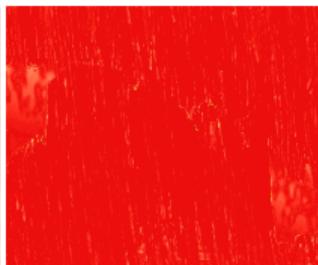
DDN
CVPR 17



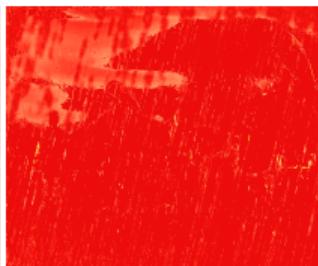
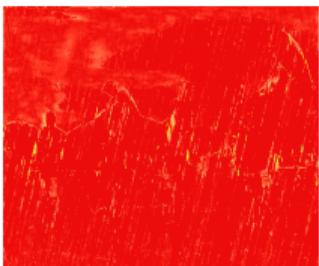
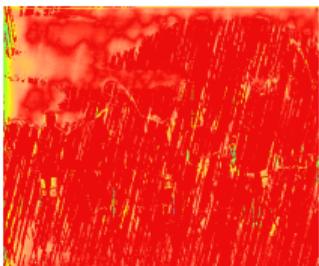
RESCAN
CVPR 19



RCDNet
CVPR 20

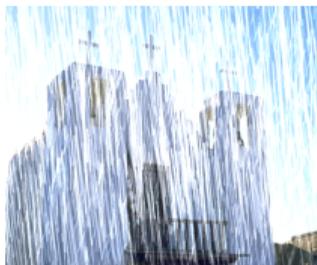


Ours

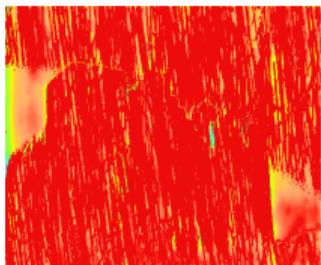


Visualizing Reconstruction Errors for Rain-Streak Removal

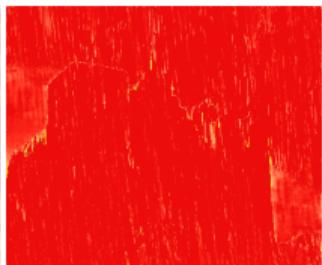
Input Rainy Image



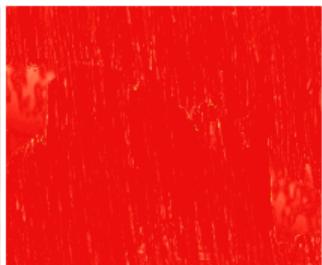
DDN
CVPR 17



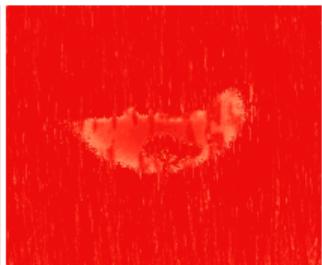
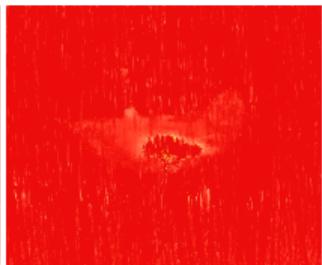
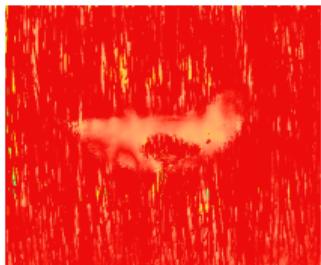
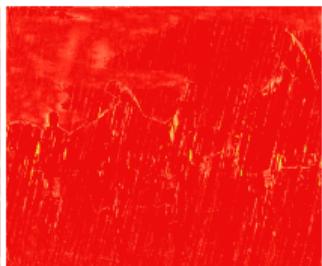
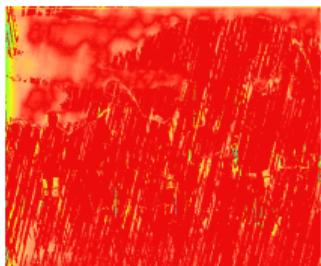
RESCAN
CVPR 19



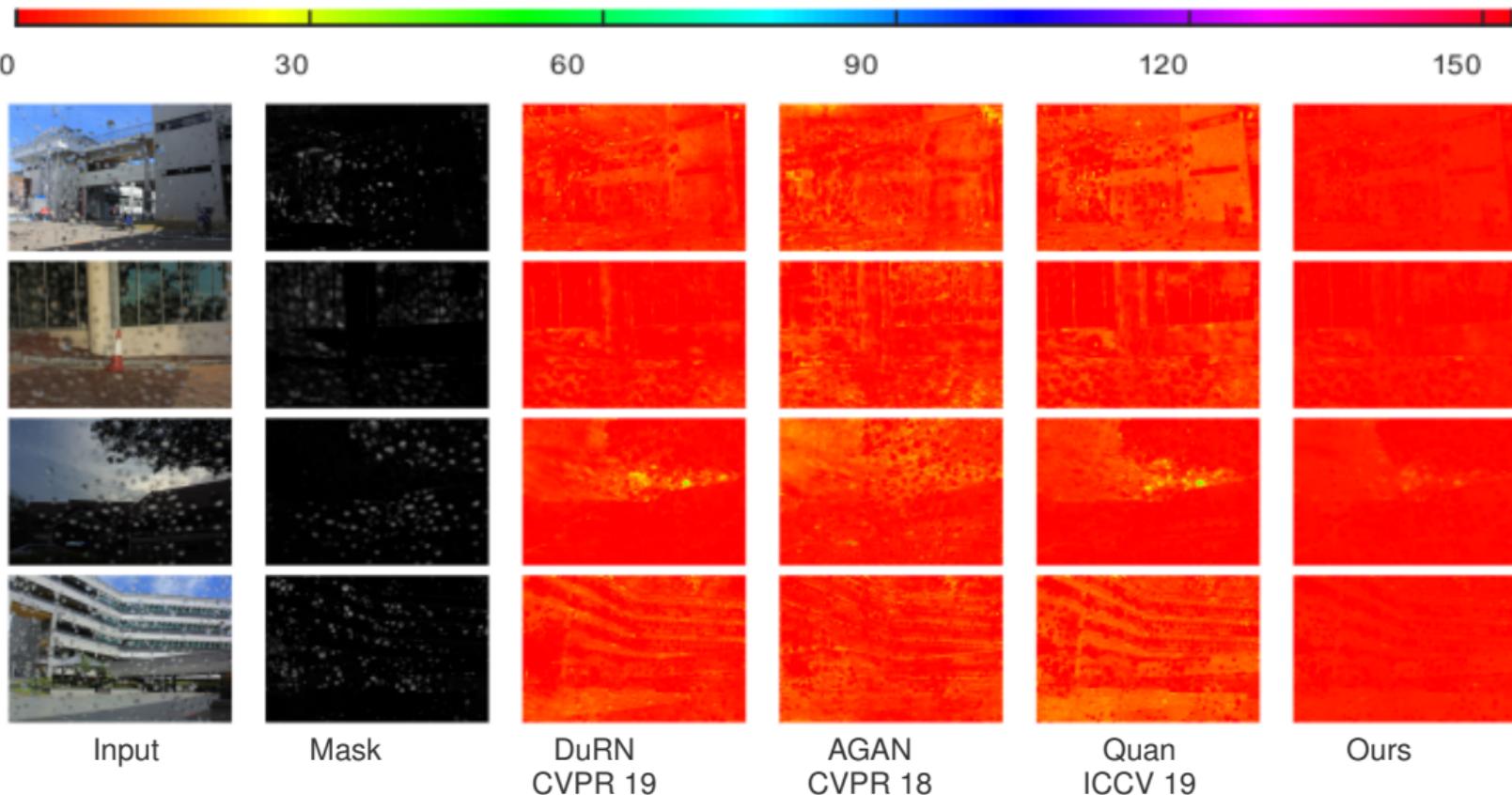
RCDNet
CVPR 20



Ours



Visualizing Reconstruction Errors for Raindrop Removal



CONCLUSIONS



Raindrop

Rain Streak

Shadow

Motion Blur



<https://kuldeeppurohit.github.io/spair/>



<https://github.com/human-analysis/spatially-adaptive-image-restoration/>